MEASUREMENTS BY MEANS OF THE ELECTROMETER TRIODE

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ABSTRACT. Different purposes, for which Philips Electrometer Triode, type 4060, can be used, have been described with special references to the measurement of voltage. It is pointed out that when the voltage source has a high resistance, this particular tube can be used, in a circuit identical in principle with an ordinary valve voltmeter, in order to measure the voltage.

In engineering and in scientific research work where during the measurement it is often necessary to measure voltages, no current—or only a negligible amount of current—is drawn from the source. This necessity arises, for instance, in cases where the voltage source has a very high internal resistance or where any current taken by the measuring instrument would cause the voltage source to vary. For such measurements it is possible to use electrostatic voltmeters or electrometers (the electroscope, the quadrant electrometer, the string electrometer, etc.). These instruments, however, are very expensive and call for the most elaborate precautions if they are to give reliable results. Furthermore, they do not lend themselves to embodiment in a compact, transportable measuring device.

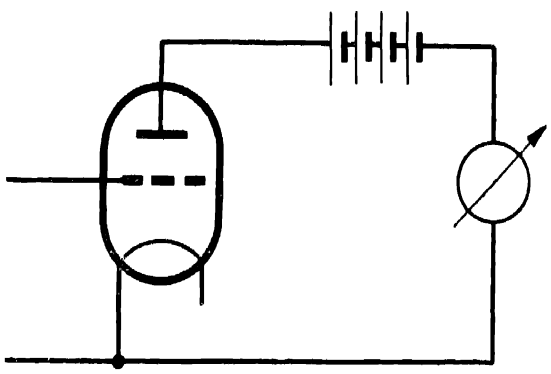

FIGURE 1
Theoretical circuit diagram

These disadvantages can be avoided by making use of an electronic valve. The electrometer triode is particularly suitable as a valve for the electrometer. A device incorporating a valve of this type is in the first place a more simple, robust and convenient arrangement. In addition it has a much smaller inertia and enables the voltage in question to be amplified to a practically unlimited extent. A circuit embodying an electrometer valve (figure 1) is, in principle, identical with a " valve voltmeter " as used for the measurement of alternating voltages at radio frequencies. The voltage to be measured is applied to the grid of an electrometer valve. At the same time, a measuring instrument responding to current variations is connected in the anode circuit. Whilst an ordinary " valve voltmeter " is not usually subject to any special requirements in regard to its input resistance, a measuring device for the purpose mentioned above does have to fulfil certain conditions in this respect. In the case of a standard type electrometer, the input resistance—or the current taken by the instrument—is purely a question of the insulation of the various parts. In a measuring device embodying an electrometer valve, the amount of current taken is determined by the grid current of this valve, which consists of a very small ionic current and a leakage current across the insulation of the grid The grid current in an ordinary radio valve is of the order of 2×10^{-7} amp., which is usually much too high for the present purpose. It is, therefore, necessary to use a special type of valve which is so constructed that the grid current is reduced to a minimum.

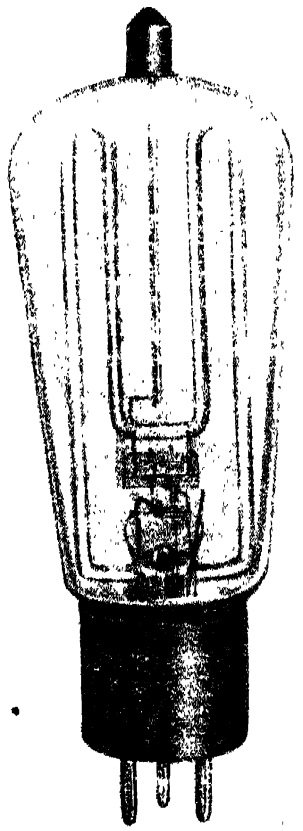

FIGURE 2
Philips Electrometer triode, type 4060

Figure 2 shows the Philips Electrometer Triode, type 4060. The control electrode (the grid of an ordinary triode) is in this case constructed as a plate, like the anode. The filament is positioned between this control electrode and the anode. The control electrode is insulated by two glass "rods," each about 4 inches in length. With this construction the leakage path is very long. The ionic current is kept very small by taking steps to ensure a good vacuum and by using a very low anode voltage, *viz.*, about 4 volts. As a result of these precautions, the total grid current corresponding to point A in the characteristic of this valve (figure 3) is only about 2×10^{-15} amp. (mean value).

As already mentioned, electrometers are used chiefly in the following special cases: (1) if the use of an ordinary measuring instrument (*e.g.*, a galvanometer) would cause the voltage source to vary on account of the load; (2) if the voltage source has a very high internal resistance, and (3) if very small quantities of electricity have to be measured.

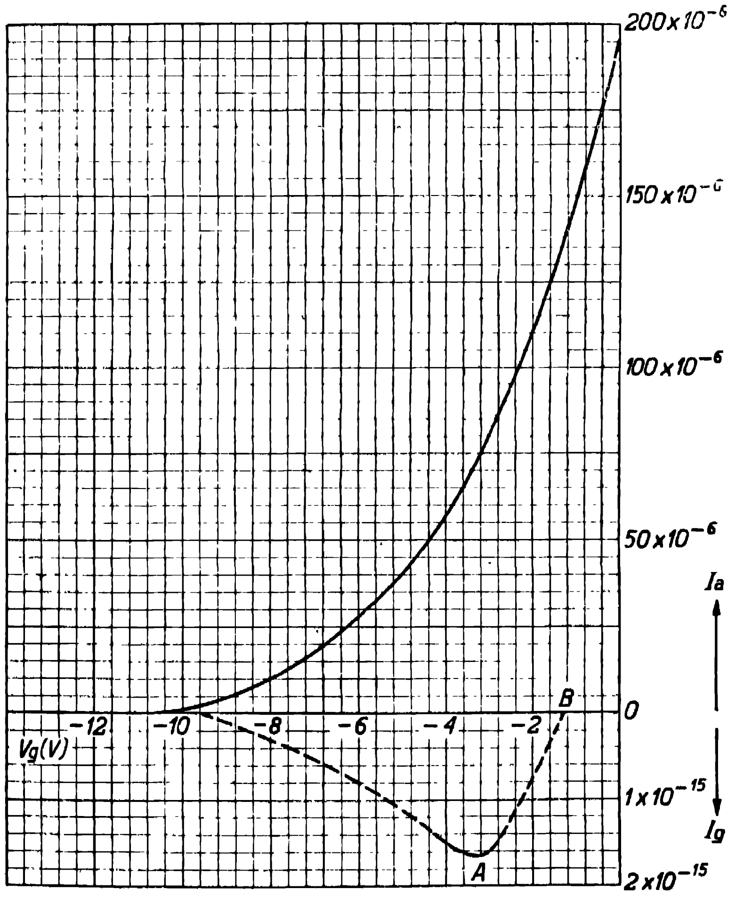

FIGURE 3
Anode current and grid current as a function of the grid voltage of the electrometer triode, type 4060, at an anode voltage of 4 volts

Examples of case (1) are afforded by certain electrochemical measurements, for instance, pH measurements. The pH value of a solution is a measure of the concentration of hydrogen ions and hence an indication of the acidic or basic activity of the solution. This measurement is frequently carried out in chemical laboratories and works, in the laboratories of institutions for testing foodstuffs and agricultural products, in medical research work and in dairies. The pH value is found by measuring the rise of voltage which takes place between a "hydrogen electrode" immersed in the solution and another electrode. The hydrogen electrode is now frequently replaced by a glass electrode which offers many practical advantages but has a very high resistance. No current may be drawn from the electrode during the voltage rise, as this would cause polarisation of the solution and give an incorrect voltage reading. To make the measurement possible, a controllable voltage is connected in opposition and adjusted to such a value that a galvanometer in the circuit gives a zero indication. This counter-voltage is then measured with a voltmeter or by comparison with a standard cell. If there is a slight error in the adjustment of the counter-voltage, the current which flows will be determined by the difference between the voltage to be measured and the reference voltage and also by the resistance of the circuit. This current will cause a deflection of the galvanometer and polarisation will occur. In order to show the voltage difference while drawing practically no current from the source, an electrometer should be used. In the case of a glass electrode the resistance of the circuit is very high (several megohms), which alone justifies the use of an electrometer.

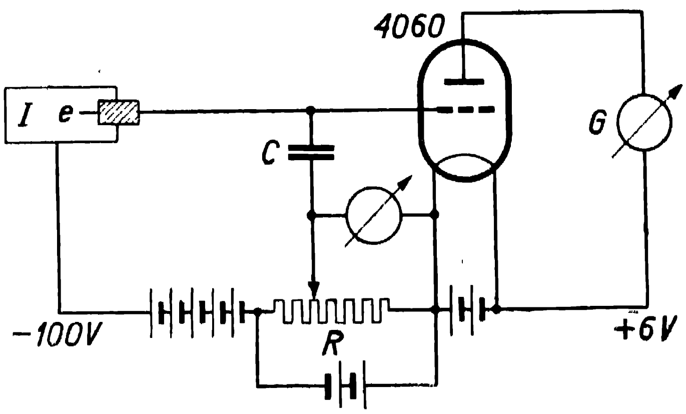

FIGURE 4

Circuit for measurement of minute quantity of electricity

An example of voltage measurement of a source having a very high internal resistance, is the measurement of very faint light intensities, for instance, when taking photometric records of stars or of spectral lines. For this purpose a photo-electric cell is usually employed. The current delivered by this cell is proportional to the light intensity and in this case it is extremely small. In order to measure these very minute currents, a very high coupling resistance must be used. In such cases it is usual to work with liquid resistances of the order of 10^9 to 10^{10} ohms. Currents of, say 10^{-10} to 10^{-11} amp, which are too small for measurement with a galvanometer, yield a voltage of about 0·1 volt on resistances of these magnitudes. The problem is how to measure this voltage without a shunt being formed by the measuring instrument across the coupling resistance. The electrometer answers this purpose ideally. A measuring device embodying the above-mentioned Electrometer Triode, type 4060, passes a current of less than 10^{-14} amp., so that currents down to 10^{-13} amp. can be measured with relatively high accuracy.

The third example : Measurement of very small quantities of electricity is met with in researches on radio-activity, providing in this case a means of counting the α, β and γ radiations. The charge measured indicates the intensity of the radiation. For these measurements the rays are trapped in an ionisation chamber, where they liberate gas ions. These gas ions are collected on an electrode in the ionisation chamber, and the increase of the electric charge of this electrode per unit of time is a measure of the radiation. The mean current produced by the ion-borne charge is extremely small, being of the order of 10^{-12} amp. and again it is necessary to measure the voltage, without drawing current from the pick-up electrode. The usual procedure is to combine the electrode with a calibrated condenser which is very well insulated and to measure the voltage across the condenser after a certain time. From this voltage the value of the charge can be directly deduced. At the normal point of operation the grid current of the Electrometer Triode, type 4060, is a few times 10^{-15} amp., which is very small compared with the electric charge of the condenser per unit of time. With most measurements the increase of voltage across the condenser is very slow, so that it is possible, by controlling an auxiliary voltage applied to the grid, to maintain the total grid voltage at such a value that the grid current is always nil (point B in figure 3). This method is described by Clay in *Physica* 4-1937, page 124 and page 654. The principle is indicated in figure 4. First the grid voltage is set at such a value that the grid current is nil. Under the action of the radiation to be measured, the chamber I becomes ionised and the liberated negative charges are attracted by the electrode. Condenser C is charged and the grid of the electrometer triode gradually becomes more negative. At the same time, however, the potentiometer R is controlled in such a manner that the galvanometer G in the anode circuit is maintained as nearly as possible at its initial deflection. At a moment when the anode current is absolutely identical with its initial value, the time lapse is accurately measured and also the voltage on the potentiometer. It is then known that in this period of time the voltage on the condenser C has increased by exactly the same amount by which the voltage on the potentiometer was adjusted in order to keep the anode current constant. The amount of this adjustment can be read directly on a voltmeter connected across R.

By the application of this principle it is also possible to measure very small photo-electric currents.

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